AGREED

Director of SAO RAS

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APPROVED BY
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Russian Telescope Time Allocation Committee
Circular Letter

The following radiometric complexes are being announced for use at the radio telescope RATAN-600 of the Federal State Budgetary Institution of Science of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) since the beginning of 2024:

1. A complex of continuum radiometers at 1.45-30.0 GHz (1.45, 2.25, 4.7, 8.2, 11.2, 14.4, 22.3 and 30.0 GHz) with bandwidths from ~4% (at dm wavelengths) up to ~17% (at cm wavelengths) of the central frequency on the secondary mirror № 1
2. A complex of continuum radiometers at 4.7-22.3 GHz (4.7, 8.2, 11.2, 14.4 and 22.3 GHz) with bandwidths from ~4% (at dm wavelengths) up to ~10-12% of the central frequency on the secondary mirror № 2.
3. Multibeam radiometric complex at 2.25, 4.7 and 14.4 GHz for the fast radio bursts (FRB) searching on the secondary mirror № 5.
4. Solar spectral-polarization complex at 3-18 GHz on the secondary mirror № 3.
5. Solar spectral-polarization complex at 1-3 GHz on the secondary mirror № 3.
6. A complex of continuum radiometers at 4.7, 8.2 and 30 GHz (in test mode) on the secondary mirror № 3.

A brief description of radiometric complexes and the corresponding observational methods (M1-M6) implemented at RATAN-600 can be found below. Detailed information can be found in the library of the SAO RAS or at the home page http://www.sao.ru and https://rat.sao.ru/ in the user manual section.

A complex of continuum radiometers at 1.45-30.0 GHz (1.25, 2.25, 4.7, 8.2, 11.2, 14.4 and 22.3 GHz) with bandwidths from ~4% (at dm wavelengths) up to ~17% (at cm wavelengths) of the central frequency on the secondary mirror № 1

M 1: the spectral flux density measurement in the frequency range of 1.45-30.0 GHz.

A complex of continuum radiometers at 4.7-22.3 GHz (4.7, 8.2, 11.2, 14.4 and 22.3 GHz) with bandwidths from ~4% (at dm wavelengths) up to ~10-12% of the central frequency on the secondary mirror № 2

M 2: the spectral flux density measurement in the frequency range of 4.7-22.3 GHz.

Multibeam radiometric complex at 2.25, 4.7 and 14.4 GHz for the fast radio bursts (FRB) searching on the secondary mirror № 5

M 3: the spectral flux density measurement in the frequency range 2.25-14.4 GHz with a high temporal resolution (up to 62.5 μs).

Responsible person for the methods 1-3: laboratory of continuum radiometers:
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Technical features. The current level of the RATAN-600 detecting equipment is provided by the ultra-low-noise, uncooled amplifiers. The standard radiometers parameters are presented in the Tables 1a-c. Designations: f_0 – central frequency (GHz); Δf - bandwidth (GHz); ΔF - sensitivity by the spectral flux density per unit of the resolution element (mJ/beam); $HPBW_x$ - width of the diagram for declination at half power level δ~42°, AR - angular resolution for altitudes δ~42°.

The RATAN-600 radiometers are the direct receivers of the microwave signals in the given frequency bandwidth with square-law detection. The operating mode of all the receivers is "total power radiometer". The data acquisition system is based on the new hardware-software subsystem ER-DAS (Embedded Radiometric Data Acquisition System) [1].

Table 1a. The continuum radiometer parameters for secondary mirror №1

f_0, GHz	Δf, GHz	ΔF, mJy/beam	$HPBW_x$, sec	AR, arcsec
30.0	5.0	100	0.75	8.5
22.3	2.5	50	1.0	11
14.4	2.0	25	1.1	13
11.2	1.0	15	1.4	15.5
8.2	1.0	10	2.0	22
4.7	0.6	5	3.2	35
2.25	0.1	30	7.2	80
1.45	0.1	20	10	110

Table 1b. The continuum radiometer parameters for secondary mirror №2

f_0, GHz	Δf, GHz	ΔF, mJy/beam	$HPBW_x$, sec	AR, arcsec
22.3	2.5	95	1.5	16.5
14.4	2.0	50	1.6	18
11.2	1.0	30	2.1	23

8.2	1.0	20	2.7	30
4.7	0.6	10	4.8	53

Table 1c. The continuum radiometer parameters for secondary mirror №5

f_0, GHz	Δf, GHz	ΔF, mJy/beam	$HPBW_x$, sec	AR, arcsec
13.40-15.40	2.0	50	1.0	11
4.40-4.55	0.15	10	3.2	35
4.55-4.70	0.15	10	3.2	35
4.70-4.85	0.15	10	3.2	35
4.85-5.00	0.15	10	3.2	35
2.21-2.29	0.80	40	7.2	80

The wide frequency band of 600 MHz of each radiometer at 4.7 GHz is divided into 4 "narrow" sub-channels of 150 MHz. A quadratic detector is installed at the output of each "narrow" channel. The data are recorded in the "Total power radiometer" (TPR) mode, so the radiometric complex consists of 16 independent radiometers. Dividing the 600 MHz band into 4 sub-channels allows to measure the dispersion of radio waves in an interstellar medium. The presence of such dispersion is a sign of a distant radio source (instead of local interference). Signals are recorded using a standard data acquisition system with a frequency of 16384 counts per second for each of the 16 channels. Four radiometers on the second mirror №5 with the RATAN-600 Western sector allow to observe 4 adjacent parts of the sky simultaneously, thereby expanding the view field 4 times. In agreement with the responsible observer the observations are carried out in the survey mode, in the form of hourly one-dimensional scans at a fixed elevation. At the beginning of 2024 the Western sector elevation corresponds to the microquasar Cyg X-3 declination. The Method 3 can be implemented jointly and in agreement with the SAO RAS responsible for methods person.

In 2024, radiometers continuum complex of secondary mirror №5 was supplemented with two continuum radiometers at the frequencies 2.3 and 14.4 GHz.

Method of observation. Observations with radiometers continuum complex (methods 1-3) are carried out in the mode of radio sources passing through a stationary beam pattern due to the daily rotation of the Earth.

Antenna parameters. The angular resolution of the radio telescope depends on the antenna elevation. Its value by declination is three to four times worse than in the right ascension, due to the knife-shaped beam pattern. The detection limit of the radio telescope is about 5 mJy (accumulation time 3 sec) at 4.7 GHz at average antenna angles under good weather conditions.

RATAN-600 is a reflector radio telescope with a variable profile antenna [2-7]. That means, both the aperture and focal length of its antennas change depending on the sources under investigation elevation. The antenna elevation varies from 3.5° to 97°. The focal length varies from 155 m from the center of the circle (the focal length measured from the antenna is f=288-155=33 m) to -40 m (f=288+40=328 m). The aberration zone in the focus of the secondary mirror changes significantly: the greater the focal length, the less the focal image of the source is distorted. This RATAN-600 geometry feature gives the advantage to get quasi-simultaneous radio spectra of sources at the frequency range 1.25-22.3 GHz within 3-5 minutes. Independent observations can be carried out with two antenna sectors in three configurations: the Northern sector (elements with numbers 487-712), the Southern sector (elements with numbers 45-255), the Southern sector with a Flat reflector (main mirror from 75 to 255 element and 120 elements of Flat reflector). The following declination ranges are available:

(i) Northern sector: -42°<DEC<+50° (it is necessary to use the "fixed" focus mode at low declination).

(ii) Southern sector:

in the upper culmination: +72°<DEC<+90°,

in the lower culmination: +49°<DEC<+90°.

(iii) Southern sector with a Flat reflector: -42° <DEC <+71°.

Observations with the Northern sector (azimuth 0°) are carried out on the radiometric complex of the secondary mirror №1. The number of installations in the Northern sector should not exceed 85 units per day.

Observations with the Southern sector and the Southern sector with a Flat reflector are performed on radiometric complexes of secondary mirrors №2 and №3 (see the methods 2 and 4, respectively). Observations with the secondary mirror №2 are carried out in azimuths of 180° and 0°. On the secondary mirror №3, symmetrical multi-azimuth observations relative to the meridian (A = 0°) are carried out. The number of installations during observations with the Southern sector with a Flat reflector should not exceed 80 units per day.

Information on secondary calibration sources, as well as special calibration sources for the low RATAN-600 elevations, can be obtained from papers 8-10. Features of calibration coefficients dependences on the antenna elevation (calibration curves) of the R-600 are presented in papers [11-12].

BIBLIOGRAPHY

1. P.G. Tsybulev, N.A. Nizhelsky, et al., RATAN-600 continuum radiometers, Acta Astrophysica Taurica No 3 2023.

2. Tsybulev, P. G. New-Generation Data Acquisition and Control System for Continuum Radio-Astronomic Observations with RATAN-600 Radio Telescope: Development, Observations, and Measurements Astrophysical Bulletin 66 (1), 109-123 (2011), 2011AstBu..66..109T.

3. Khaikin S.E., Kaidanovskii N.L., Pariiskii IU.N., Esepkina N.A, Radioteleskop RATAN-600, Izvestiia Glavnoi astronomicheskoi observatorii v Pulkove; no. 188, Leningrad: Izd. Glavnoi astronomicheskoi observatorii v Pulkove, 1972., p. 3-12 (1972), 1972IzPul.188....3K.

4. Stotskii A.A., Aberratsii glavnogo zerkala antenny peremennogo profilia i skanirovanie diagrammy napravlennosti putem smeshcheniia obluchatelia, Izvestiia Glavnoi astronomicheskoi observatorii v Pulkove; no. 188, Leningrad: Izd. Glavnoi astronomicheskoi observatorii v Pulkove, p. 63-76 (1972), 1972IzPul.188...63S.

5. Pariiskii IU.N. and Shivris O.N., Metody radioastronomicheskogo ispolzovaniia RATAN-600, Izvestiia Glavnoi astronomicheskoi observatorii v Pulkove; no. 188, Leningrad: Izd. Glavnoi astronomicheskoi observatorii v Pulkove, p. 13-39 (1972), 1972IzPul.188...13P.

6. Pariiskii Yu.N., Shivris O.N., Korol'kov D.V., et al., The RATAN-600 radio telescope. Commencement of operation and study of first sector, Radiophysics and Quantum Electronics, Volume 19, Issue 11, pp.1099-1107 (1976), 1976R&QE...19.1099P.

7. Y. N. Parijskij, IEEE Antennas Propagation Magazine 35, 7 (1993), 1993IAPM...35....7P.

8. Korzhavin A.N., An investigation of VPA [variable profile antenna] depending on aperture illumination using the method of optical simulation, Astrofiz. Issled. Izv. Spets. Astrofiz. Obs., Tom 9, p. 53-70 (1977), 1977AISAO...9...53K.

9. J.W.M. Baars, R. Genzel, I.I.K. Pauliny-Toth and A. Witzel, The absolute spectrum of CAS A - an accurate flux density scale and a set of secondary calibrators , A&A 61, 99-106 (1977), 1977A&A....61...99B.

10. M. Ott, A. Witzel, A. Quirrenbach et al., An updated list of radio flux density calibrators , A&A, 284, 331 (1994), 1994A&A...284..331O.

11. R.A. Perley and B.J. Butler, An accurate flux density scale from 1 to 50 GHz, Aph. J. Suppl. 204, article id. 19, 20 pp. (2013).

12. Udovitskiy R.Yu., Sotnikova Yu.V., Mingaliev M.G., et al., Automated data reduction system for observation with the RATAN-600, Astrophysical Bulletin, Volume 71, Issue 4, pp.496-505, 2016, 2016AstBu..71..496U.

13. Aliakberov K.D., Mingaliev M.G., Naugol'naya M.N., Determination of the flux densities of radio sources on the set of broadband continuous-spectrum radiometers for the RATAN-600 radio telescope, Bulletin of the Special Astrophysical Observatory - North Caucasus, Vol. 19, p. 59 – 65 (1985), 1985BSAO...19...59A.

METHOD 4

Solar spectral-polarization complex at 3-18 GHz on the secondary mirror № 3

M 4: The radio emission intensity and polarization measurement of the discrete radio sources and the Sun in a dynamic range up to 60 dB at 3-18 GHz

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The functionality of the complex is related with a significant increase in the dynamic range for the purpose of registering reference sources in the microwave waveband at the levels of both the limiting sensitivity for this instrument and for recording the brightest radio sources on the Sun reaching millions of degrees of the antenna temperature. This is achieved by the introduction of automatic attenuators on the signal amplification lines across all channels of the complex. The complex can be used for a variety of antenna measurements, as well as for powerful signals from geostationary satellites. The complex was installed in 2016 in the RATAN-600 receive cabin № 3, which is working at the southern sector antenna system with a Flat reflector for conducting multiple observations of the dynamics of the Sun in azimuths and in tracking modes.
A full power mode of the receivers with registration of right and left circular polarizations on all channels is realized.
All necessary features of the complex during the observations, such as the rapid analysis and full reduction of observations are also realized in the automatic mode. The format of the observational data is consistent with the observational database existing since 1995.
Complex features are given in Table 2.

Table 2. Parameters of complex at the frequencies of 3-18 GHz with the secondary mirror № 3 RATAN-600.

Parameter	Value
Frequency range	3.0 GHz – 18 GHz
Levels of frequency resolution	1st level: 80 channels, bandwidth of 100 MHz 2nd level: 10 channels, bandwidth of 1500 MHz
Registration speed	0.0025 sec/112 channels
Noise temperature	300 K
Dynamic range	>60 dB
Inter-channel decoupling	>20 dB
Ellipticity	1-5 %
The width of the horn diagram in the entire range	+-60 degrees
The decoupling between the RH and LH polarizations	> 20 dB
The offset of the phase centers for RH and LH	0.5 mm

Solar spectral-polarization complex at the frequencies of 1-3 GHz with the secondary mirror № 3

M 5: The radio emission intensity and polarization measurement of the discrete radio sources and the Sun in a dynamic range up to 90 dB at the frequencies 1-3 GHz.

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The purpose of the complex is a detailed study of the spectra of radio astronomical signals of left and right polarizations (with a resolution of up to 1.2·105 Hz) and a time resolution of 8 μs under conditions of severe contamination of the range with industrial and household radio interference (Table 3). The dynamic range of the complex is sufficient both for registering reference sources in the microwave range at levels of maximum sensitivity for this equipment, and for registering the brightest radio sources on the Sun, reaching millions of degrees of antenna temperature. A distinctive feature of the complex is the direct digitization of the radio astronomy signal by high-speed ADCs, followed by processing of the digital signal by a powerful FPGA (programmable logic integrated circuit) and calculation of the signal power spectral density in real time. The dynamic range is ensured by the use of low-noise, temperature-stabilized amplifiers at the radiometer input with an inherent noise temperature of no higher than 100K and the presence of an AGC in the analog part of the radiometer. The equipment's noise immunity is ensured by the presence of notch filters with high rectangularity to suppress the most powerful sources of radio interference and the use of the kurtosis method, implemented on an FPGA, for statistical processing of the incoming digital signal in real time and filtering non-Gaussian components. The complex can be used for spectral antenna measurements.

The complex was installed in 2023 in the receiving cabin №3 RATAN-600 in the Southern Sector antenna system with a Flat reflector to conduct multiple observations of the solar dynamics in azimuths and in tracking modes. Full power mode with registration of right and left circular polarizations is implemented. Observations at the complex are carried out automatically. The format of the observational data is consistent with the observational database existing since 1995.

Table 3. Parameters of complex at the frequencies of 1-3 GHz with the secondary mirror № 3.

Parameter	Value
Frequency range	1.0 GHz – 3 GHz
Frequency resolution	Optional: from 122kGz to 1 GHz
Time resolution	from 8.3 ms
Noise temperature	40-100 K
Dynamic range	90 dB
Ellipticity	1-10 %
The width of the horn diagram	at least 90 degrees
The decoupling between the RH and LH polarizations	> 15 dB
The offset of the phase centers for RH and LH	no more than 0.005 m along the focal line and 0.04 m normal to the horn aperture

BIBLIOGRAPHY

1. Bogod V.M., Lebedev M.K., Ovchinnikova N.E., Ripak A.M., Storozhenko A.A. Shlenzin S.V. SPECTRORADIOMETRY OF THE SOLAR CORONA ON THE RATAN-600 RADIO TELESCOPE, Cosmic Research, 2023, Vol. 61, pp.27-33.
2. Ripak A. M., Bogod V. M., Grenkov S. A., and Lebedev M. K., RFI-Resistant Decimeter Band Radiometer for the RATAN-600 Radio Telescope, Astrophysical Bulletin, vol. 78, №4 pp. 622–634, 2023.
3. Богод В.М. Стороженко А.А., Перваков А.А. Отчет об испытаниях комплекса с высоким динамическим диапазоном. Июнь-декабрь, 2016г
4. Bogod V. M., RATAN-600 radio telescope in the 24th solar-activity cycle. I. New opportunities and tasks, Astrophysical Bulletin, vol. 66, №2 pp. 190–204, 2011.
5. Bogod V. M., Alesin A. M., and Pervakov A. A., RATAN-600 radio telescope in the 24th solar-activity cycle. II. Multi-octave spectral and polarization high-resolution solar research system, Astrophysical Bulletin, vol. 66, №2, pp. 205–214, 2011.
6. Baldin S. V. and Garaimov V. I., RATAN-600 radio telescope in the 24th solar-activity cycle. III. System of data acquisition and control of the solar spectral facility, Astrophysical Bulletin, vol. 66, № 3, pp. 371–378, 2011.
7. Tokhchukova S. K., RATAN-600 radio telescope in the 24th solar activity cycle. IV. Information system for RATAN-600 solar observations, Astrophysical Bulletin, vol. 66, № 3, pp. 379–388, 2011.

METHOD 6

Continuum radiometers complex at 4.7, 8.2 and 30 GHz (in test mode) on the secondary mirror № 3

M 6: the spectral flux density measurement of radio emission from space objects at frequencies 4.7, 8.2 and 22.3 GHz in multi-azimuth mode

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The 8.2 GHz radiometer is built on the basis of an 8.2 GHz radiometric module designed and manufactured by Mikran. Module operating parameters:

Center frequency 8.2 GHz (wave 3.7 cm)
Operating frequency range 7.7 -8.7 GHz
Noise factor for 10 copies. 0.61 - 0.69dB (44 -50 K)
Gain in the operating band 63-68 dB
Supply voltage 8-12 V
Current consumption no more than 170 mA
Waveguide input with a cross-section of 28.5x12.6 mm2, coaxial SMA output

Structurally, the module is made of an input low-noise amplifier (LNA), combined with a coaxial-waveguide junction, an output LNA and a bandpass filter, mounted on a copper plate and connected by cable assemblies. The radiometer is made in the form of a separate receiving device mounted on duralumin plates and consists of a primary feed, a waveguide transition from a round to a rectangular cross-section 28.5x12.6 mm^2, a directional coupler with a transition attenuation of 42 dB for the calibration signal, a radiometric module, broadband (0.1-18 GHz) microwave detector optimized with a low-frequency preamplifier (LOF), as well as power supplies, data acquisition system and radiometer control.

The 4.7 GHz radiometer is built on the basis of the Mikran radiometric module, which is a microwave part of a direct gain radiometer with a total gain of 72 dB (15 million times the power!) and a bandpass filter (BPF) at the output. Structurally, the module is made of 4 sub-modules (input low-noise amplifier (LNA), two linear amplifiers and a band-pass filter (BPF)), interconnected by rigid coaxial cable assemblies. The input of the modules is waveguide, the output is coaxial (SMA), noise figure is 0.35 – 0.45 dB (24-32K, 10 copies). The only items missing are microwave detectors and low-frequency preamplifiers (LFPAs), which are designed in-house to facilitate matching with a high-speed data acquisition system. The 4.7 GHz radiometer is similar to those installed on receive cabins № 1 and № 2, which differ from the four-horn system of receive cabin № 5 only in the absence of division of the wide 600 MHz band into 4 subbands of 150 MHz each.

The 30 GHz radiometer is built on the basis of the MARS-3 radiometric module and operates in total power mode. Installed at the edge of the focal line.
The parameters of the radiometers are given in Table 4.

Table 4. Parameters of radiometers from the secondary mirror № 3.

f_0, GHz	Δf, GHz	ΔF, mJy/beam	HPBWx, sec
30	5.0	200	11
8.2	1.0	20	30
4.7	0.6	10	53

BIBLIOGRAPHY

1. P.G. Tsybulev, N.A. Nizhelskij, и др., Радиометры континуума радиотелескопа РАТАН-600. Известия Крымской астрофиз. Обсерватории, 2023, 119, №3, 26-30.